Eutrophication

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Introduction

Eutrophication describes the biological effects of an increase in the concentration of nutrients. The collective term ‘nutrients’ refers to those elements that are essential for primary production by plants or other photosynthetic organisms. Eutrophication is most often caused by increases in the availability of nitrogen and phosphorus, commonly present in soil and water in the form of nitrate and phosphate, respectively. However, altered concentrations of any plant nutrient may have a recognizable biological effect. Eutrophication can occur in any aquatic system (freshwater or marine), and the term is also used to describe the process whereby terrestrial vegetation is affected by nutrient-enriched soil water.

This OpenLearn course provides a sample of level 2 study in Environment & Development

Learning Outcomes

After studying this course, you should be able to:

- describe the principal differences between a eutrophic and an oligotrophic ecosystem
- explain the mechanisms by which species diversity is reduced as a result of eutrophication (*Questions 2.1 and 2.2*)
- contrast the anthropogenic sources that supply nitrogen and phosphorus to the wider environment, and describe how these sources can be controlled (*Question 3.1*)
- describe how living organisms can be used as monitors of the trophic status of ecosystems (*Question 4.1*)
- compare the advantages and disadvantages of three different methods for combating anthropogenic eutrophication (*Question 4.2*).

1 Introduction

1.1 Origin of the term ‘eutrophication’

The levels of nutrients present determine the trophic state of a water body, where trophic means ‘feeding’.

SAQ 1

Give another example of the adjective *trophic* being used in a scientific context.

Answer

Trophic levels, as applied to a food chain.

The adjective *eutrophe* (literally ‘well fed’) was first used by the German botanist Weber in 1907, to describe the initially high nutrient conditions that occur in some types of ecosystem at the start of secondary succession. Scientists studying lakes at the beginning of the 20th century identified stages in plant community succession that appeared to be directly related to trophic state or nutrient status. They described a series of stages:

‘oligotrophic — mesotrophic — eutrophic — hypertrophic’

where **oligotrophic** meant ‘low in nutrients’, **mesotrophic** ‘with intermediate nutrient concentration’, **eutrophic** ‘high in nutrients’ and **hypertrophic** ‘very high in nutrients’. At the time, these definitions were derived from comparative estimates between water bodies with different nutrient status, judged according to their **phytoplankton** communities. Phytoplankton is a collective term for the free-floating photosynthetic organisms within the water column. It encompasses both algae (from the kingdom Protoctista) and photosynthetic members of the kingdom Bacteria. Thus an oligotrophic lake would have clear water with little phytoplankton, whereas a eutrophic lake would be more turbid and green from dense phytoplankton growth, and a mesotrophic lake would be intermediate between the two. Table 1.1 summarizes some of the general characteristics of oligotrophic and eutrophic lakes. A further definition, **dystrophic**, describes ‘brown-water lakes’, which have heavily stained water due to large amounts of organic matter usually leached from peat soils. The presence of these organic compounds can reduce the availability of nutrients to organisms, making the water body even less productive than an oligotrophic one.

Table 1.1 Some general characteristics of oligotrophic and eutrophic lakes.

Characteristic	Oligotrophic	Eutrophic
primary production	low	high

diversity of primary producers	high species diversity,with low population densities	low species diversity,with high population densities
light penetration into water column	high	low
toxic blooms	rare	frequent
plant nutrient availability	low	high
animal production	low	high
oxygen status of surfacewater	high	low
fish	salmonid fish (e.g.trout, char) often dominant	coarse fish (e.g. perch, roach, carp) often dominant

SAQ 2

Why is light penetration poor in eutrophic lakes?

Answer

The high density of phytoplankton absorbs light for photosynthesis and prevents it penetrating deeper into the water.

More recently, **trophic bands** have been defined in relation to levels of nutrients measured by chemical analysis. Table 1.2 shows trophic bands as defined in relation to concentrations of total phosphorus.

Table 1.2 Trophic bands for standing waters. (Phosphorus concentrations tend to be higher in running waters that carry suspended sediment.)

Trophic band	Total phosphorus/mg l^{-1}
dystrophic	<0.005
oligotrophic	0.005-0.01
mesotrophic	0.01-0.03
eutrophic	0.03-0.1
hypertrophic	>0.1

The trophic state of water bodies and rivers varies depending on a number of factors, including position in the landscape and management of surrounding land. In general, upland areas are more likely to have nutrient-poor (oligotrophic) water, characterized by relatively fast-flowing rivers (Figure 1.1) and lakes that have clear water with limited higher plant communities.

Figure 1.1 Fast-flowing upland stream with clear water and few plants.

By contrast, lowland waters in more fertile river catchments tend to be nutrient-rich (eutrophic), and lakes in lowland areas are more likely to be turbid with lush fringing vegetation. Lowland rivers have slower flow and are likely to be more nutrient rich as a result of soluble compounds having been washed into them. They are likely to have fringing vegetation and some floating and submerged aquatic plants (Figures 1.2 and 1.3). In aquatic systems, the term macrophyte is used to describe any large plant (*macro*, large; *phyte*, plant). The term is used to distinguish angiosperms (whether emergent, floating or submerged) from small algae such as **diatoms** (which are strictly not plants at all, but are often lumped together with plants when considering the productivity of ecosystems).

Figure 1.2 Lowland river, rich in aquatic plant species.

Figure 1.3 Rich community of macrophytes. The tall plants growing out of the water are described as emergent.

SAQ 3

What is the process by which nutrient elements are lost from the soil profile by the action of excess rainfall draining through it, which may eventually deliver them to a surface water body?

Answer

Leaching.

The term ‘eutrophication’ came into common usage from the 1940s onwards, when it was realized that, over a period of years, plant nutrients derived from industrial activity and agriculture had caused changes in water quality and the biological character of water bodies. In England and Wales, eutrophication has been a particular concern since the late 1980s, when public awareness of the problem was heightened by widespread toxic blue-green bacterial blooms (commonly, but incorrectly, referred to as algal blooms) in standing and slow-flowing freshwaters. Figure 1.4 shows blue-green bacteria (cyanobacteria) growing at the margins of a lake. Cyanobacteria are not typical bacteria, not only because some of them are photosynthetic, but also because some of them can be multicellular, forming long chains of cells. Nonetheless, cyanobacteria clearly belong to the kingdom Bacteria because of their internal cellular structure.

Figure 1.4 A cyanobacterial bloom.

SAQ 4

Why are cyanobacteria so productive in eutrophic water bodies (Figure 1.4) compared with oligotrophic ones?

Answer

The ready availability of nutrients allows rapid growth. In oligotrophic water the rate of growth is limited by the nutrient supply, but in eutrophic water it is often only the availability of light which regulates primary production.

1.2 Resource availability and species diversity

A wide range of ecosystems has been studied in terms of their species diversity and the availability of resources. Each produces an individual relationship between these two variables, but a common pattern emerges from most of them, especially when plant diversity is being considered. This pattern has been named the humped-back relationship and suggests diversity is greatest at intermediate levels of productivity in many systems (Figure 1.5).

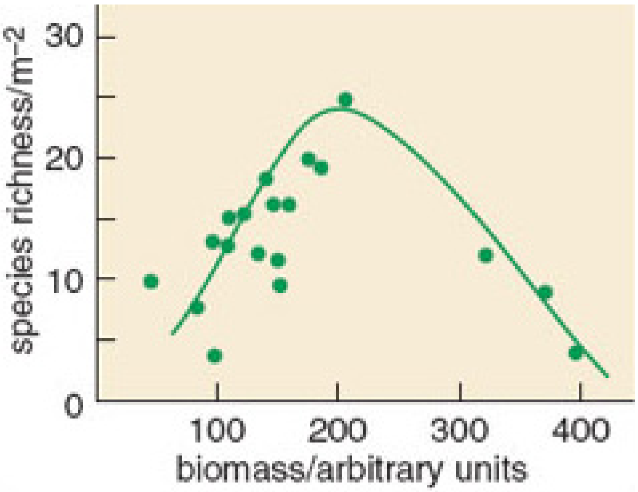

Figure 1.5 The species richness of samples of vegetation from South Africa shows a classic humped-back relationship with ecosystem productivity as inferred from amount of biomass per unit area.

SAQ 5

How does species diversity differ from species richness?

Answer

Species diversity includes a measure of how evenly spread the biomass is between species (equitability) rather than a simple count of the species present.

An explanation for this relationship is that at very low resource availability, and hence ecosystem productivity, only a limited number of species are suitably adapted to survive. As the limiting resource becomes more readily available, then more species are able to grow. However, once resources are readily available, then the more competitive species within a community are able to dominate it and exclude less vigorous species.

In most ecosystems it is the availability of mineral nutrients (especially nitrogen and phosphorus) that limits productivity. In eutrophic environments these nutrients are readily available by definition, so species diversity can be expected to be lower than in a more mesotrophic situation. It is for this reason that eutrophication is regarded as a threat to biodiversity. Eutrophication of the environment by human-mediated processes can have far reaching effects, because the nutrients released are often quite mobile. Together with habitat destruction, it probably represents one of the greatest threats to the sustainability of biodiversity over most of the Earth.

1.3 Natural eutrophication

Eutrophication of habitat can occur without human interference. Nutrient enrichment may affect habitats of any initial trophic state, causing distinctive changes to plant and animal communities. The process of primary succession is normally associated with a gradual eutrophication of a site as nutrients are acquired and stored by vegetation both as living tissue and organic matter in the soil.

There is a long-standing theory that most water bodies go through a gradual process of nutrient enrichment as they age: a process referred to as **natural eutrophication**. All lakes, ponds and reservoirs have a limited lifespan, varying from a few years for shallow water bodies to millions of years for deep crater lakes created by movements of the Earth's crust. They fill in gradually with sediment and eventually became shallow enough for plants rooted in the bed sediment to dominate, at which point they develop into a closed swamp or fen and are eventually colonized by terrestrial vegetation (Figures 1.6 and 1.7).

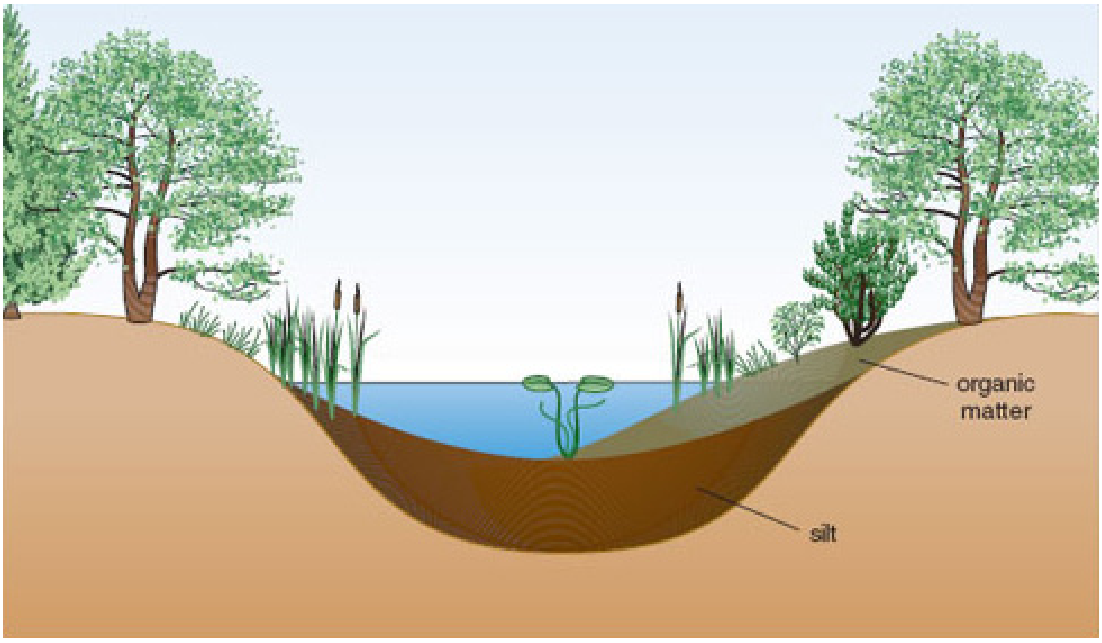

Figure 1.6 Cross-section through a water body that is gradually becoming filled with silt deposits and organic matter as a result of vegetation growth.

Figure 1.7 A floodplain water body becoming colonized with emergent macrophytes, which may eventually cause it to disappear through an accumulation of silt and organic matter.

Nutrient enrichment occurs through addition of sediment, rainfall and the decay of resident animals and plants and their excreta. Starting from an oligotrophic state with low productivity, a typical temperate lake increases in productivity fairly quickly as nutrients accumulate, before reaching a steady state of eutrophy which might last for a very long time (perhaps thousands of years). However, it is possible for the nutrient status of a water body to fluctuate over time and for trophic state to alter accordingly. Study of sediments in an ancient lake in Japan, Lake Biwa (believed to be around four million years old) suggests that it has passed through two oligotrophic phases in the last half million years, interspersed with two mesotrophic phases and one eutrophic phase. Evidence such as this has led to the suggestion that the nutrient status of lakes reflects contemporary nutrient supply, and can increase or decrease in response to this. The processes by which nutrients are washed downstream or locked away in sediments help to ensure that reversal of natural eutrophication can occur.

Rivers vary in trophic state between source and sea, and generally become increasingly eutrophic as they approach sea-level.

1.4 Human-induced eutrophication

While eutrophication does occur independently of human activity, increasingly it is caused, or amplified, by human inputs. Human activities are causing pollution of water bodies and soils to occur to an unprecedented degree, resulting in an array of symptomatic changes in water quality and in species and communities of associated organisms. In 1848 W. Gardiner produced a flora of Forfarshire, in which he described the plants growing in Balgavies Loch. He talked of 'potamogetons [pondweeds] flourishing at a great depth amid the transparent waters, animated by numerous members of the insect and finny races'. These 'present a delightful spectacle, and the long stems of the white and yellow water lilies may be traced from their floating flowers to the root'. By 1980, the same loch had very low transparency and dense growths of planktonic algae throughout the summer. The submerged plants grew no deeper than 2 m, and in the 1970s included just three species of *Potamogeton*, where previously there were 17.

For any ecosystem, whether aquatic or terrestrial, nutrient status plays a major part in determining the range of organisms likely to occur. Characteristic assemblages of plant and associated animal species are found in water with different trophic states. Table 1.3 shows some of the aquatic macrophyte species associated with different concentrations of phosphorus in Britain.

Table 1.3 Concentrations of phosphorus (in rivers) with which plant species are correlated.

Phosphorus present as soluble reactive phosphorus (SRP)*/mg P l-1	Plant species (see Figure 1.8 for illustrations)
<0.1	bog pondweed, *Potamogeton polygonifolius* river water-crowfoot,*Ranunculus fluitans*
0.1-0.4	fennel-leaved pondweed, *Potamogeton pectinatus*
0.4-1.0	yellow water-lily,*Nuphar lutea* arrowhead, *Sagittarias agittifolia*
>1.0	spiked water-milfoil, *Myriophyllum spicatum*

* This term is explained in Section 2.1.

SAQ 6

What impression would you gain from an observation that a population of river water-crowfoot in a particular stretch of river had been largely replaced by fennel-leaved pondweed over a three-year period?

Answer

The phosphorus concentration of the water may have increased.

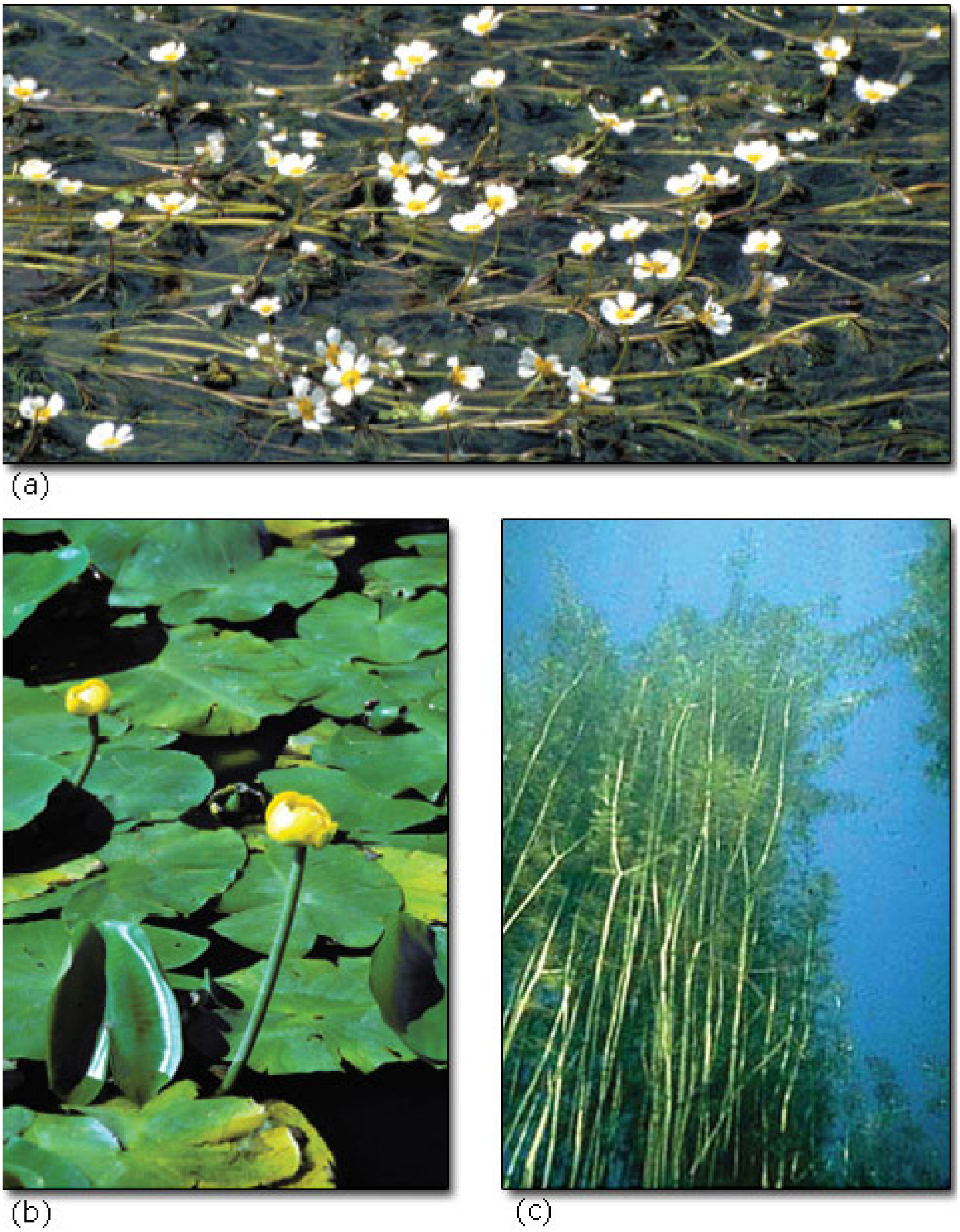

Figure 1.8 Three aquatic macrophyte species which differ in their tolerance to eutrophication: (a) river water-crowfoot (*Ranunculus fluitans*) is intolerant, (b) yellow water-lily (*Nuphar lutea*) is intermediate and (c) spiked water-milfoil (*Myriophyllum spicatum*) is tolerant.

Figure 1.9 illustrates the relationship between levels of total phosphorus in standing water and the nutrient status of lakes. Above a level of 0.1 mg phosphorus per litre, biodiversity often declines. Using the trophic bands defined in Table 1.2, this is the concentration at which lakes are considered to become hypertrophic. This is way below the standard of 50 mg l^{-1} set as the acceptable limit for phosphorus in drinking water. Nutrient loadings this high are generally caused by human activities. Extremely high levels of eutrophication are often associated with other forms of pollution, such as the release of toxic heavy metals, resulting in ecosystems that may no longer support life (Figure 1.10).